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Maximum Continuous Dynamic Flows in Networks with Flow-Dependent Transit Times

関西学院大学大学院理工学研究科
情報科学専攻　茨木研究室　瀬島 賢治

A dynamic network has capacities and transit times on its arcs. The maximum dynamic continuous flow problem asks to obtain the maximum flow from a source to a sink within a given time bound T. Although the transit time of each arc is considered as a fixed parameter in most literature, it is also natural to assume that it depends on the flow rate on the arc, in many applications of real world; e.g., the traffic flow problem and evacuation problem.

A traditional approach to the dynamic flow problem uses the time-expanded network that contains one copy of the original network for each discrete time step. With this model, we can convert a dynamic flow in the original network to a static flow in this network. But the size of the time-expanded network often becomes enormous. Ford and Fulkerson[1] proved that there always exists a maximum flow which keeps sending constant flows on some paths from a source to a sink as long as the flow along the path reaches its sink within time bound T; the flow over time featuring this simple structure is called 'temporally repeated'. Based on this observation, they showed that the maximum dynamic flow problem can be solved in polynomial time by computing the associated minimum cost flow of the original network. The problem solved by this approach is defined on the discrete-time horizon, and it may be interesting to extend it to the continuous-time horizon, as attempted by Fleischer and Tardos[2].

In this talk we consider the maximum dynamic continuous flow in a network, in which the transit time of each arc is dependent on the flow rate. For this, we introduce four assumptions. (1) The flow speed in an arc is determined by the inflow rate at the tail of the arc, (2) the flow speed does not change until arriving at the head of an arc (transit time is given by the ratio of the arc length over the speed), (3) the transit time is a non-decreasing and convex function of the flow rate, and (4) each arc has transit time plasticity (i.e., the transit time of an arc never decreases even if the flow rate decreases afterward). Under these assumptions we extend the result of Ford and Fulkerson and show that the maximum dynamic continuous flow, which consists of a set of step flows with temporally repeated property, can be obtained by solving the associated minimum cost flow problem of the original network.

By some computational experiment we show that this method can handle comparatively large size networks.